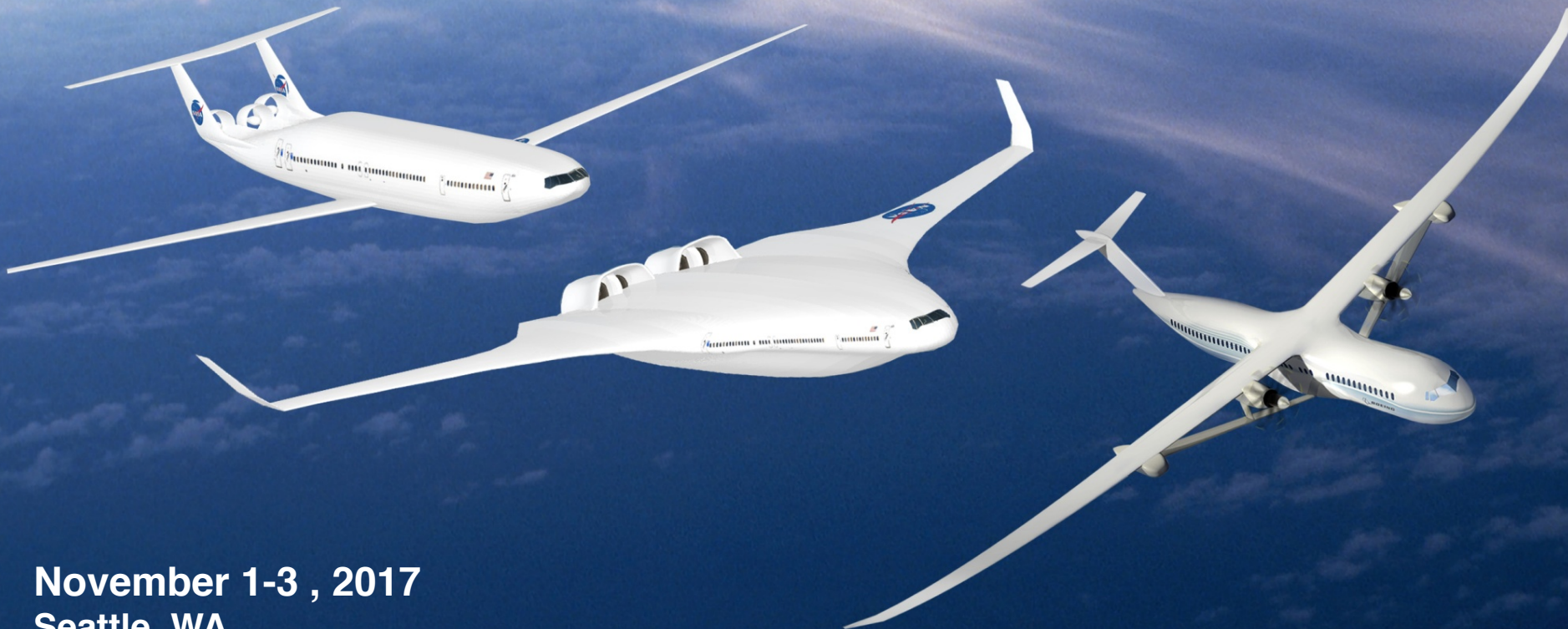


Overview: Performance Adaptive Aeroelastic Wing

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ACGSC Meeting



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Seattle, WA

Applications for the Performance Adaptive Aeroelastic Wing equipped with the Variable Camber Continuous Trailing Edge Flap (VCCTEF)

- **Configuration optimization for drag reduction**

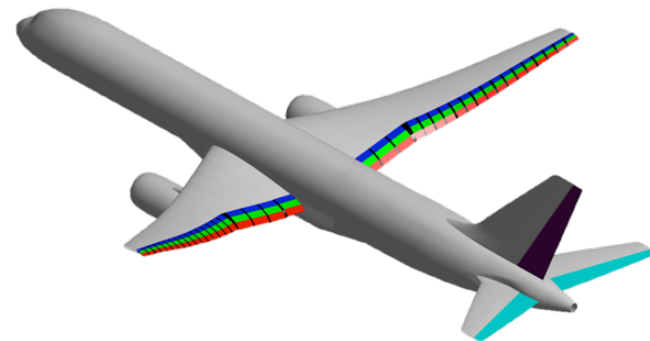
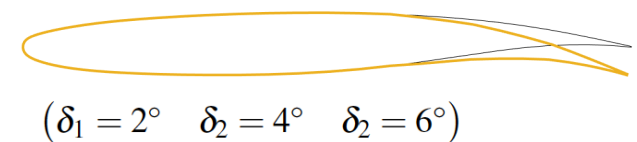
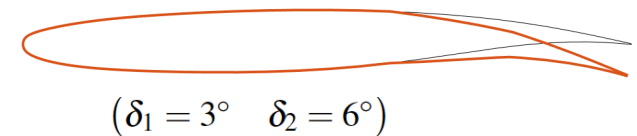
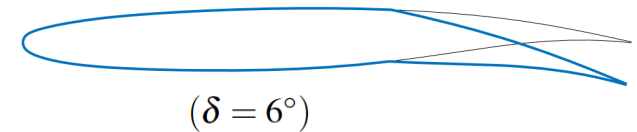
- Rapid aero-structural solver
- Optimal configuration study

- **Real-time drag minimization**

- Algorithm development
- Wind tunnel demonstration

- **Multi-objective control**

- Gust load alleviation
- Maneuver load alleviation
- Drag-cognizant control



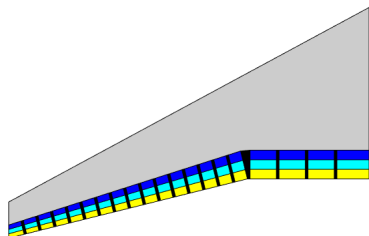
Configuration optimization for drag reduction



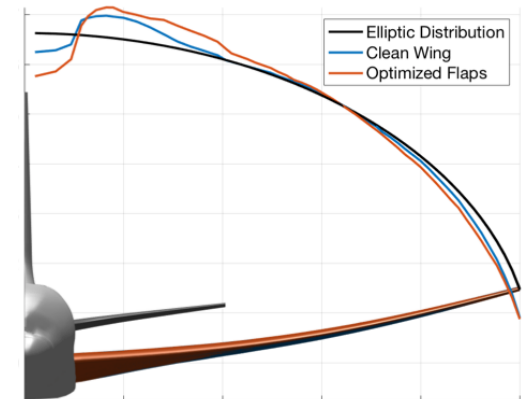
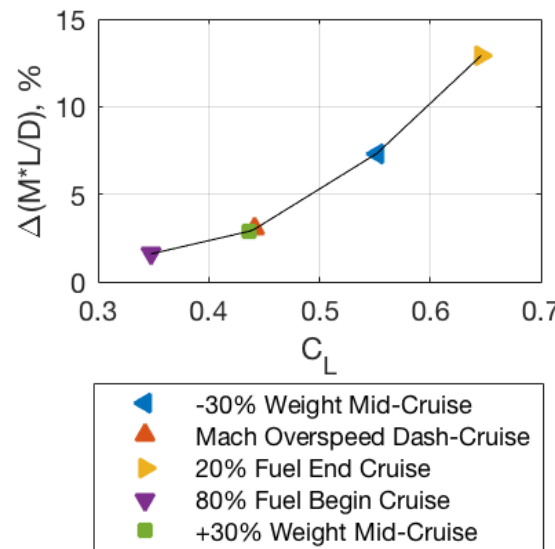
- Analyzed VCCTEF configuration to determine an optimal drag-reducing arrangement and deflection profile
- High fidelity CFD is impractical, rapid aero-structural solver with reasonable accuracy needed to help narrow the design space
- Developed a vortex lattice method with transonic and boundary layer corrections
 - 3% error when compared to CFD
 - 26x faster than Euler-based model
- Optimization results identify “best” configuration that provides 8% drag benefit
 - parabolic deflection
 - 3 camber segments
 - 4-16 outboard flaps



Parabolic-3 configuration
($\delta_1 = 1^\circ$ $\delta_2 = 3^\circ$ $\delta_3 = 6^\circ$)



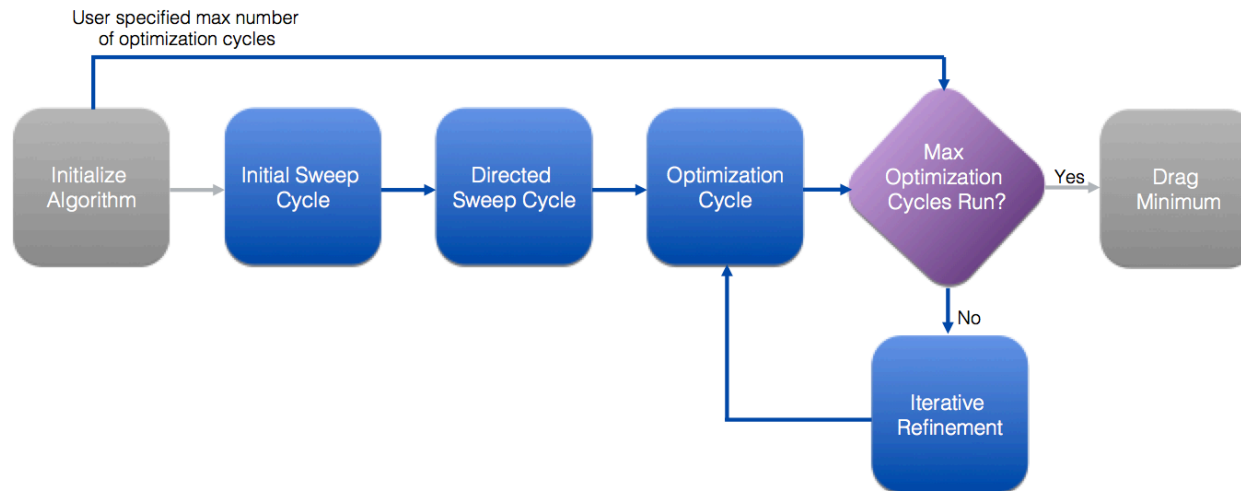
-4-16 configuration



Real-time drag minimization



- Developed a real-time drag optimization algorithm for aeroelastic wings with wing-shaping control
 - Recursive least-squares system identification of aerodynamic lift and drag model
 - Optimization based on Newton-Raphson nonlinear solve of quadratic drag surrogate model



Initial sweep: Aerodynamic lift model estimated

Directed sweep: Drag approximation model estimated for design lift

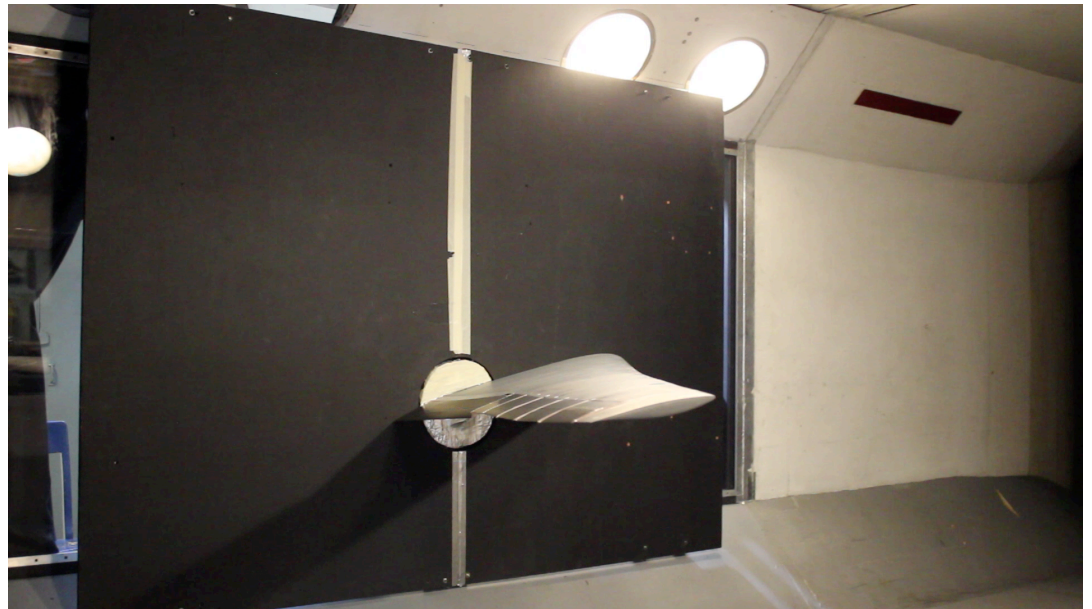
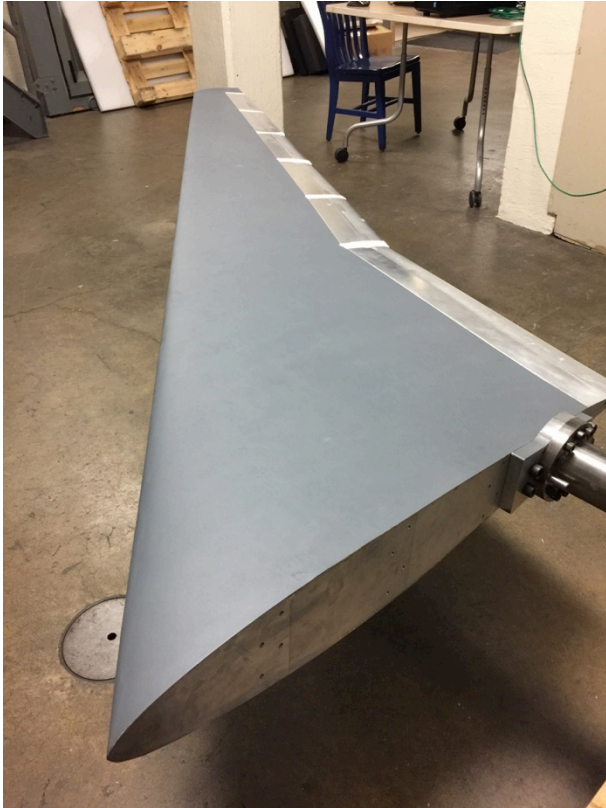
Optimization: Nonlinear solve to identify flap solution corresponding to drag minimum

Iterative Refinement: Random perturbations about flap solution to refine surrogate model

Real-time drag minimization



- Subscale wind tunnel test of VCCTEF-equipped flexible wing conducted
 - SBIR Phase 2 agreement with Scientific Systems Company, Inc. and University of Washington Aeronautical Laboratory
 - Follow-on test planned to address actuator failures



Gust and maneuver load alleviation



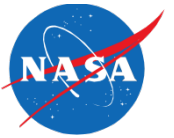
- Designed controller for flexible wings utilizing the VCCTEF to mitigate gust and maneuver loads as measured through *wing root bending moment* M_y
- Gust and some quantities poorly known
 - Generate adaptive estimates
 - Results in time-varying control gains, solve Riccati equation online
- Multi-objective control formulation addresses several goals simultaneously
 - Cost function and weights used to combine potentially competing objectives
 - Can combine with use of nominal controller
- Cost function for gust load alleviation (GLA):

$$J = \lim_{t \rightarrow \infty} \frac{1}{2} \int_0^t \left(\overbrace{q_f \hat{x}^T G_x^T Q G_x \hat{x}}^{\text{Modal suppression}} + u_a^T R u_a + \overbrace{q_M \hat{M}_y^T \hat{M}_y}^{\text{Load alleviation}} \right) dt$$

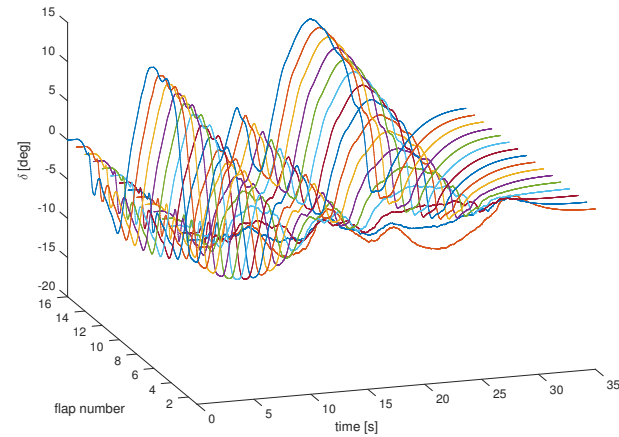
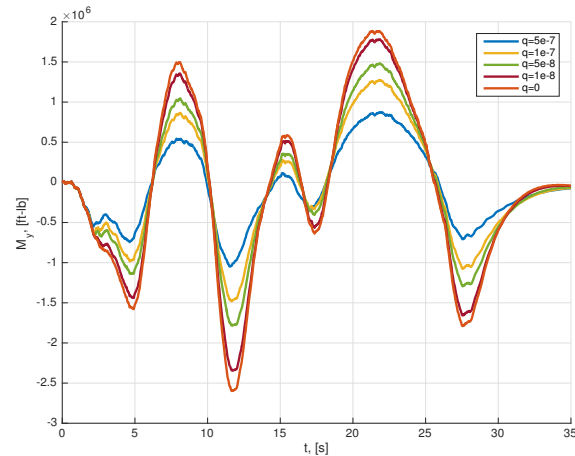
$\hat{M}_y = \hat{M}_x \hat{x} + \hat{M}_{u_n} \underbrace{u_n}_{\text{Tracking}} + \hat{M}_{u_a} u_a + \hat{M}_w \hat{w}$

- Wind tunnel test for GLA planned as part of SBIR Phase 2x agreement with Scientific Systems Company, Inc., University of Washington Aeronautical Laboratory, and Boeing

Gust and maneuver load alleviation



- Gust load alleviation applied to Generic Transport Model



- Maneuver load alleviation

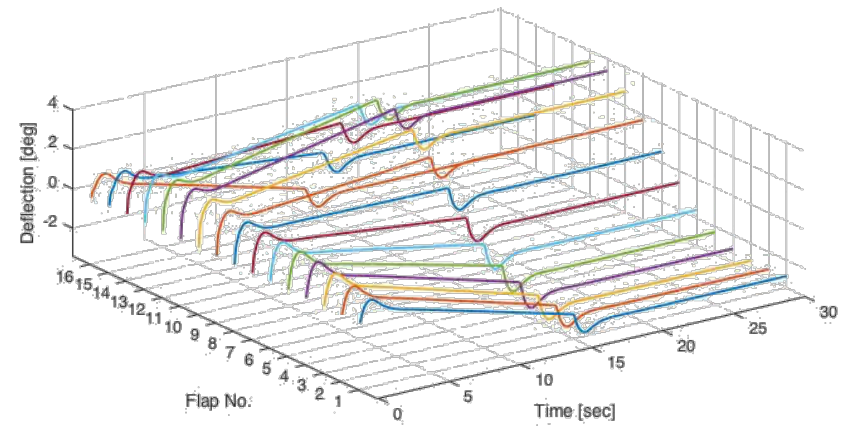
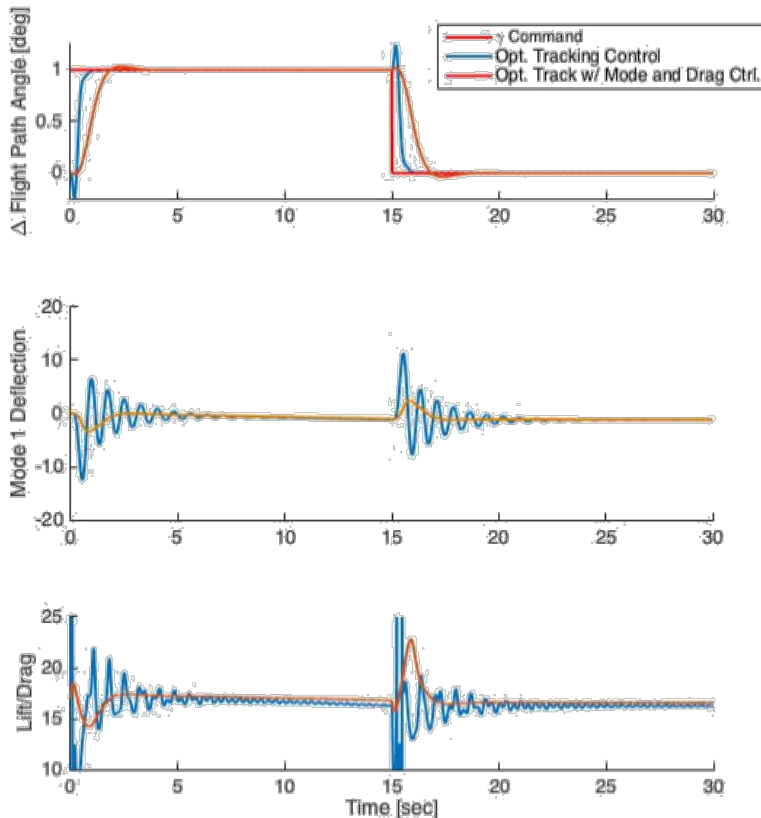
Baseline Pitch Rate Control

Drag-cognizant control



- Multi-objective formulation easily accommodates other goals, such as drag reduction

$$J = \lim_{t \rightarrow \infty} \frac{1}{2} \int_0^t (q_f \hat{x}^T G_x^T Q G_x \hat{x} + u_a^T R u_a + q_D \Delta C_D) dt$$



Baseline Flight Path Control



Questions?